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Dust Inhalation by Hematite Miners

The Prevention of Lead Poisoning in Industry: Part I. The Indiarubber Industry (Methods of Concentration of Controlled Risk)

Determinations of Air Dustiness with the Sugar Tube, Palmer Apparatus, and Impinger, Compared with Determinations with the Konimeter

The Effect of Turbulent Air Motion and of Humidity on the Stability of Dust, Fume, and Smoke Clouds

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DUST INHALATION BY HEMATITE MINERS*

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Acting H. M. Medical Inspector of Mines

A BRANCH of the study of the pneumonokonioses which has received slight attention is that centering round the inhalation of hematite dust by machine drillers in iron ore mines.

In September, 1918, Dr. E. L. Collis submitted an unpublished report on a visit to the Cumberland iron ore mines, and as the result of his pertinent observations X-ray examinations were made in certain cases of these iron ore miners. The results of the screen examinations were stimulating, but were not, however, followed up by clinical and other investigations, and in consequence no very definite conclusions were then formulated.

In April, 1925, however, Sir Kenneth Goadby read a paper at Sheffield on fibrosis of the lung in iron ore miners, surveying the existing knowledge of the subject and differentiating pathologically between silicosis and iron stone fibrosis.

In October of the same year, at the request of the Health Advisory Committee of the Mines Department, I was afforded facilities for making a complete clinical investigation of the question in the ore field in Cumberland and North Lancashire.

INVESTIGATION OF WORKING CONDITIONS IN IRON ORE MINES

The first step was, of necessity, to establish the fact that hematite dust is generated in sufficient quantity and in sufficiently minute size to cause pulmonary trouble if inhaled by these drillers; consequently at the Sir John Walsh, Florence, Ullcoats, and Newton mines underground inspections of all varieties of working places were made, the different types of machines were seen in action, and the various methods of drilling observed.

* Received for publication Feb. 24, 1926.

Machines may be divided into two classes, *wet* and *dry*. The wet drills, which were seldom seen, give rise to no dust as, by the introduction of a stream of water down the drill, the substance drilled emerges as a thick paste. On the other hand, dry drills (usually of the hammer type, the main type of drill employed) give rise to an intense dust which is blown directly back into the face of the operator. Drills are almost invariably used in "developing;" in such places, from the absence of a through current of air, ventilation is often (of necessity) poor, and the air distinctly stagnant. Even when artificial ventilation is provided by a powerful exhaust fan as, say, in a sinking, my experience was that the atmosphere breathed by the driller is heavily charged with dust.

There is no other conclusion but that drillers using the dry machines inhale an atmosphere heavily impregnated with dust. Further, although the men realize that they are breathing the dust, only quite a small percentage protect themselves by wearing wet flannel or sponge masks.

Nature of the Dust Inhaled

The main geologic formations which the driller meets in these mines are hematite and limestone. Other formations exist, but either are not drilled, or do not give rise to dust, or are of such extreme rarity as to be negligible.

Hematite varies from a very hard, dry substance to a softer, moist material which is seldom drilled, but simply got out by the pick. The softer form, even when drilled, gives rise to little or no dust; hard hematite, on the other hand, produces a fine, dry, powdery dust, the composition of which (as revealed by six analyses) is shown in Table 1. The silica is probably present as such and not as a silicate; the iron is present as a sesquioxide.

TABLE 1.—SIX ANALYSES SHOWING COMPOSITION OF DUST FROM HARD HEMATITE

MOISTURE	SILICA	LIME	IRON		PHOS.
			Wet	Dry	
%	%	%	%	%	%
4.81	12.66	2.32	53.62	56.33	0.0068
4.40	12.93	2.38	53.84	56.32	0.0066
4.35	13.62	2.17	53.57	56.01	0.0066
4.56	13.46	2.18	53.73	56.29	0.0067
5.02	13.31	2.16	53.78	56.62	0.0064
4.62	13.36	2.02	53.67	56.27	0.0068

Clinical Study

Having briefly dealt with the conditions favoring dust inhalation and also the nature of the material inhaled, it was next necessary to consider the effects of dust inhalation. One hundred drillers taken from all over the area and sixteen nondrillers (men who had worked underground for a term of years without being exposed to the dust, chosen to serve as controls) were carefully interrogated and examined clinically. Among these 100 drillers were three men who had worked in the South African gold mines. The statements and findings in each of these 116 cases are not given here in detail, as it may be sufficient to give simply the salient facts and deductions which were obtained.

Drillers

Medical History.—The medical history of these drillers was particularly clear. Some had been drilling as long as thirty years without being off work for a single day through illness. Among the 100 subjects the only illnesses contracted during the period spent in drilling were a few cases of mild influenza, one case of lumbago, one of neuritis, another of rheumatism, and two of pleurisy.

Symptoms Reported.—Twenty-seven per cent. of the men made no complaint whatsoever. Nevertheless a large proportion of men definitely admitted certain symptoms arising from the inhalation of the dust. Further, these symptoms were very constant in different districts, a fact which rules out the possibility of collusion among the men and considerably strengthens the evidence. Such symptoms may be divided into immediate, or transitory, and permanent. Immediate symptoms were an irritation of the nose and throat during drilling, a "clogged-up" feeling, and a tendency to hawk up the dust for a short period when coming out of the mine; but permanent cough was a symptom particularly absent.

By far the most constant of the permanent symptoms was shortness of breath, an admission often made by young men. This shortness of breath was not experienced at rest, but only on exertion of varying degrees of severity from the merest climbing of a hill in severe cases to the use of a drill in mild cases. This shortness of breath on exertion, however, was much in excess of the normal and was *not* to be explained by symptoms of cardiac insufficiency nor was it correlated with symptoms of other lung diseases such as asthma, bronchitis, or with large-lunged emphysema. Symptoms indicative of pulmonary tuberculosis, *i.e.*, loss of weight, night sweats, cough, etc., were constantly lacking, except in the cases of men who had been drilling in South Africa. Of these three men, two gave definite symptoms pointing to phthisis, which was absolutely confirmed on physical examination.

Physical Examination.—The physical examination of these men revealed certain striking facts, particularly outstanding when contrasted first with the physical condition of the men who had drilled in South Africa, and then with the condition of the controls, *i.e.*, men who had been working underground in the hematite mines for many years, but who had not been exposed to the dust.

Sixty-four of the 100 drillers examined could be classed clinically as possessing normal chests or conversely as affording at least no distinct clinical evidence of pathologic change in the lungs. On the other hand, while 6 per cent. were doubtful, 30 per cent. showed very well-defined and constant features, which were, in the order of their importance:

1. Loss of ability to expand the chest fully on forced inspiration. In producing this expansion the subjects were able to use, and did use markedly, the accessory muscles of respiration.

2. An abnormal accentuation of the supraclavicular and the infraclavicular hollows, usually corresponding with a slight flattening of the chest in these regions.

3. While there was an absence of variation in the note on opposite sides, *i.e.*, evidence of patches of massive fibrosis or of pleural involvement was constantly lacking, the note elicited on percussion was in many cases generally duller and less resonant than normal.

4. In certain cases there was found a well-marked deviation from the normal breath sounds, which assumed an almost puerile or at least broncho-vesicular character. In only one case were adventitious sounds in the nature of râles and rhonchi obtained, and this was in a case of chronic bronchitis contracted ten years before the man had commenced to work underground. There was no evidence of any pleural involvement on auscultation, except in one case where over a limited area a doubtful crepitation might have existed.

Returned South African Drillers

Three men had been using dry drills in the South African gold mines. Of these men, one had escaped pulmonary damage from the silica dust of the gold mines, but, as has been stated, two gave definite indication of symptoms of pulmonary tuberculosis, which was confirmed by physical examination.

Controls

Compared with the drillers, the medical history was equally clear, but the contrast in every other respect was most marked. None of the controls made complaint of any adverse symptoms resulting from underground work; in no case was shortness of breath complained of; and in no case did physical examination of the chest reveal a departure from the normal.

Conclusions

The foregoing examination was limited to the clinical aspect and consequently presents the case from one, but not from every angle. Nevertheless certain deductions may be drawn from these clinical findings, deductions which investigations recently made in dust sampling and in pathologic examination of lung tissue tend to confirm:

1. The inhalation of hematite dust produces certain tissue changes in the lungs of iron ore drillers.

2. Such changes are not localized but are generalized or diffuse throughout both lungs, although the apices are perhaps more affected than the bases.

3. These tissue changes do not give rise to the pulmonary diseases, *i.e.*, asthma, bronchitis, pneumonia, and phthisis, which commonly result from dust inhalation, but produce the independent and striking symptom complex which has already been described.

These deductions are given additional weight by comparison with pathologic research. Clinically the results of hematite inhalation do not resemble those of silica inhalation but present a unique picture, while the sections obtained by Sir Kenneth Goadby from the lungs of an iron stone miner clearly indicated not only the presence of a considerable amount of iron as shown by differential staining but also a fibrosis which was essentially general throughout the lungs, finer and quite opposed to the nodular whorled masses of the silicotic lung.

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THE PREVENTION OF LEAD POISONING IN INDUSTRY
PART I. THE INDIARUBBER INDUSTRY
(METHODS OF CONCENTRATION OF CONTROLLED RISK)*

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IN MARCH, 1922, the British Secretary of State (Home Affairs) issued a code of Regulations, entitled "Indiarubber Regulations, 1922" (1), designed to deal with the dangers to the health of workers engaged in certain processes incidental to the manufacture of indiarubber and indiarubber goods, in particular, to: (*a*) vulcanizing by means of cold cure process or by any other process involving the use of carbon bisulphide, sulphur chloride, carbon-chlorine compounds or benzol (pure or commercial); (*b*) any process involving the use of lead or compounds of lead.

These Regulations, which became operative on May 1, 1922, have proved of value in dealing with the dangers with which they were designed to cope. The present note refers solely to the development of a simple and effective method of handling lead products in such a manner as to provide the protection which these Regulations sought to insure.

The rules for "lead processes" set out in the Regulations follow in principle those which, in recent years, have become standard in Great Britain for all processes involving exposure to lead compounds, and provide for:

(*a*) a minimum age of worker,
(*b*) exclusion of any female under 18 years of age,
(*c*) application of exhaust draught for the removal of lead dust at (or as near as possible to) the source of origin,
(*d*) provision of messrooms,
(*e*) regular supply of clean overalls,
(*f*) accommodation for clothing put off during working hours,
(*g*) provision of washing facilities,
(*h*) periodic medical examination and maintenance of health register,
(*i*) regulations as to re-employment of workers after suspension by the Certifying Surgeon, and
(*j*) the provision of facilities for the sampling of materials by H. M. Government Inspectors.

The provision of a regulation for sampling is necessary so as to enable an inspector to determine whether or not the materials in use are "lead compounds" within the meaning of the Regulations; and, therefore, whether or not the process is a "lead process" as defined therein.

A "lead process" is one in which a "lead compound" is used—the latter being any lead material which, when shaken for one hour with hydrochloric acid (in the proportion of 1 gm. of material to 1,000 c.c. of 0.25 per cent. hydrochloric acid), yields to solution lead in excess of 5 per cent. when calculated as lead oxide, the method

* Received for publication March 17, 1926.

of test being precisely detailed. This test has been used for many years past in England in connection with the use of lead compounds in the manufacture of pottery, and since 1920 it has been applied to all lead products covered by the Women and Young Persons (Employment in Lead Processes) Act, 1920 (2).

The lead compounds in use in the rubber industry are litharge, basic sulphate of lead, red lead, and white lead. In England, the quantity of litharge used far exceeds the total of all other lead compounds.

Prior to the introduction of the Indiarubber Regulations of 1922, it was the practice for rubber manufacturers to purchase their lead compounds in the form of powder for use in admixture with other powders on the slowly revolving, heated "incorporating" or "mixing" rolls, where they are incorporated with rubber. The dry powders are usually distributed by hand over the rubber as it passes through the heated rolls, and the operation is continued until the dry powder and rubber have become a homogeneous mixture.

The cases of lead poisoning which occurred in this industry were shown to be entirely (1) among workers engaged in weighing out dry lead compounds; and (2) (to a much greater extent) among workers employed on the incorporating rolls. It was clear that the source of poisoning was lead dust arising during the operations, the production of dust being very marked on the roller mills owing to the current of hot air which rises from the heated rolls. The Indiarubber Regulations of 1922 were specially designed to meet these dangers; hence the requirement as to the "application of exhaust draught . . . . at (or as near as possible to) the source of origin."

The efficacy of such a provision had previously been clearly demonstrated by Legge and Goadby (3) who instance an indiarubber factory for which records of poisoning are available before and after the application of exhaust ventilation over the heated incorporating rolls. It was shown that before the alteration was made, out of 14 men employed thereon, 10 showed a blue line, 5 were markedly anemic, 1 had weakness of the wrists, and 2 weakness of grasp. In a period of ten years after the application of exhaust ventilation, only one case had been reported.

When the Indiarubber Regulations of 1922 were introduced, it was obvious that rubber manufacturers were likely to be put to serious expense in installing the apparatus demanded by these Regulations, and that further expense would be incurred in the supervision of workers, provision of overalls, special washing accommodation, etc.; and it was apparent that these expenses would fall more heavily on the small than on the large manufacturers—the latter being in all probability already well provided with more modern appliances and general equipment. In this connection, it must be pointed out that although the total consumption of lead compounds in the rubber industry is very considerable the distribution of cases of lead poisoning bears no sensible relation to the weight distribution of the raw materials; for, as in all industries where lead is used, it is found that while controlled workers may handle large

quantities of lead compounds without ill effects, small quantities used by careless workers or unsuitable appliances give rise to a large number of cases of poisoning.

The solution of the problem which thus arose was found in the development of the principle of concentration of controlled risk in the use of lead compounds which the present writer has long advocated in numerous directions.

While the poisonous properties of lead compounds are indisputable, it is equally indisputable that such compounds can be handled without danger if adequate precautions are taken to protect the workers. Adequate protection is more easily provided and controlled when only a few workers are involved. The principle of concentration of controlled risk is effected by employing a small number of workers on processes yielding products which are much less toxic than their separate constituents and which can be safely handled without any special precautions. It is obvious that in this direction lies the only scientific and rational solution of the problem, and its application, wherever possible, should need no advocacy—happily, its adoption is growing.

The method adopted in the case of the rubber industry was for the lead manufacturer to produce mixtures of lead compounds and rubber which did not give rise to dust when handled by the operative in the rubber factory or when used in the incorporating rolls. The rubber mixtures now sold, containing 80 per cent. of lead compound with 20 per cent. of rubber, are in the form of thin sheets, homogeneous in composition. It is found that these sheets readily incorporate with the other ingredients on the mixing rolls, while the complete absence of lead dust in the operation has made it possible for the Factory Department of the British Home Office to declare that where this material is used, the Indiarubber Regulations, 1922, are not to be enforced so far as lead processes are concerned. In some instances, 80 parts of lead compounds are incorporated with 20 parts of wax and the solid product so obtained is used in the mixing rolls instead of the rubber mixture.

These mixtures are prepared in lead factories where there are already in operation the most modern methods of hygienic control, under the supervision of those daily concerned with the handling of lead products in large quantities. The use of these rubber or wax preparations entails no extra expense on the rubber manufacturer, who, while being freed from the burden of the Regulations in respect of lead compounds so used, has the additional satisfaction that his operatives are completely protected.

As an example of modern constructional hygiene, the method is sound. Instead of crippling or even destroying an industry by unnecessary expense, it allows its continuance while insuring hygienic conditions of employment, or, in the words of the late Dr. Rambousek (4), himself a distinguished hygienist of international repute:

> The parts of the industrial structure are so closely interrelated that it is not easy to measure what effect any one part will have on the other parts. There is a danger that an ill-considered interference with industry for reasons of hygiene will defeat its own

object and that those very workers whom it is sought to protect, or perhaps an equally important or numerous body of workers, will be deprived of their livelihood. Prohibition of the use of a dangerous article is a mode of dealing with the danger which is in my view somewhat childish in its simplicity, and would lead to an almost intolerable interference with the machinery of civilisation if it were applied to all the substances which are of greater danger than White Lead. Hygiene must not be merely negative in its action, its method must be to study all the factors of the industrial situation and to make a dangerous industry non-dangerous.

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DETERMINATIONS OF AIR DUSTINESS WITH THE SUGAR TUBE, PALMER APPARATUS, AND IMPINGER, COMPARED WITH DETERMINATIONS WITH THE KONIMETER*

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INTRODUCTION

RECENT comparative tests of instruments for determining atmospheric dusts have been made (1) whereby uniform suspensions of dust in air were sampled simultaneously with several dust determining instruments, including the sugar tube (2), konimeter (3), Palmer apparatus (4), and impinger (5), and the dustiness then determined by succeeding analytic processes. The results of the dust determinations by one method were compared with those by another through the medium of ratios or factors; these factors can be used to convert dustiness determined by one instrument into the terms of another. No ways are known at present for determining the absolute dustiness of air as numbers of particles per unit volume, hence comparisons of the determinations by the different instruments present the only measures of their efficiencies.

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BRIEF DESCRIPTION OF INSTRUMENTS

The sugar tube method of sampling consists of filtering 15 cubic feet of air through pure granulated sugar, which retains the dust. The sugar is then dissolved in dust free water, leaving insoluble dust particles in suspension. An aliquot portion of the solution in a Sedgewick-Rafter cell, such as is used for counting blood corpuscles, is examined under a microscope at 110 diameters magnification, and the dust particles are counted. From this result the number of dust particles per cubic centimeter of air is figured.

The konimeter employs an entirely different principle. The instrument is hand size and consists of a cylinder and piston actuated by a spring which draws 10 c.c. of air at high velocity through a nozzle about 0.6 mm. in diameter. The nozzle is held 0.5 mm. above a glass plate, coated thinly with vaseline; dust in the air impinges against the vaseline and adheres thereto, forming a spot about 1 mm.

in diameter. The spot is examined under a microscope at 200 diameters magnification, and the visible particles are counted. The results are expressed as numbers of particles per cubic centimeter of air.

The Palmer apparatus draws the air through water in a large glass bulb; the air breaks the water into a spray that washes dust from the air. The impinger draws air at high velocity through one or more orifices against a surface submerged below water and normal to the impinging streams. The particles moving at high velocity penetrate into the water, which retains them. The method of counting the dust particles caught by the Palmer apparatus and the impinger is similar to that used with the sugar tube.

The median 1.5 was found as the best average of all the ratios of the numbers of particles of silica dust per cubic centimeter of air determined by the sugar tube to the numbers determined by the konimeter, whereas 6.4 was the ratio determined in previous investigations in granite cutting plants (6). However, the results indicated that the ratio is higher for high degrees of dustiness and lower for low degrees of dustiness. Further calculations showed that the numbers of particles of silica dust determined by the sugar tube are related to those determined by the konimeter according to the empirical equation

$$y = 107x^{0.293}$$

where x = the number of particles of dust determined by the sugar tube and y = the number of particles of dust determined by the konimeter. Similar equations were given by other dusts. The equations have at present no theoretic foundation, and must be considered only as the best statement of the relations found in the range of dustiness investigated.

Cause of the Changing Ratios

The particles of air floated dust range in size from 50 microns longest diameter to very small particles beyond the range of microscopic vision (smaller than 0.5 micron[1]). Most particles are less than 10 microns longest diameter. The analyst who counts the particles counts every one he can see. The insoluble particles in the sugar solution are greatly diluted, so that considerable apparent distances remain between the particles, and the observer has no difficulty in differentiating them during the counting. Furthermore, a procedure is sometimes employed of diluting the solution more when particles are very numerous. The result is that the sugar tube procedure for counting allows little chance of miscounts due to particles becoming superimposed or lying in juxtaposition.

The konimeter spot, however, catches all particles in a fixed area. If the particles are few, the distances between them are relatively large; but the distances decrease as the number of particles increases, and this adds to the difficulty of counting. Moreover, when the number of particles is greater, the chance that one particle may lodge on top of another or alongside of it is increased. Two or more superimposed particles are seen and counted as one, and the same is often true of particles which lie

[1] One micron = 0.001 mm.

alongside each other, because the eye cannot separate the very small specks. The result is that the count of particles is less than the true number, and the discrepancy increases as the number of particles increases.

The konimeter was thus found impracticable for determining dusts in excess of 600 to 800 particles per cubic centimeter of air. Estimations of the numbers were made for concentrations up to 3,000 per cubic centimeter, but the errors were certainly large. In the higher dustiness, whole patches, as the samples were viewed under the microscope, were covered with dust particles. Estimations of the particles in a cluster were made according to the apparent projected area of the cluster compared with that of a particle. The result of such counts can be considered estimations only, which, although undoubtedly inaccurate, provide the best count possible. Thus, the konimeter method attempts to account for adjacent particles, but fails to consider superimposed particles which the observer cannot possibly see. Furthermore, when a particle during the sampling strikes upon one previously lodged, it may fail to adhere, may rebound, and be removed by the escaping air. All of these effects tend to decrease the number of particles determined by the konimetric method.

Results of Tests with Various Dusts

Comparative determinations of air floated dusts were made with the different instruments in suspensions of coal, grain, iron, limestone, and silica dusts; and some comparative determinations had been made previously in granite dust at Barre, Vt. (6). The comparisons between the results of the sugar tube and those of the

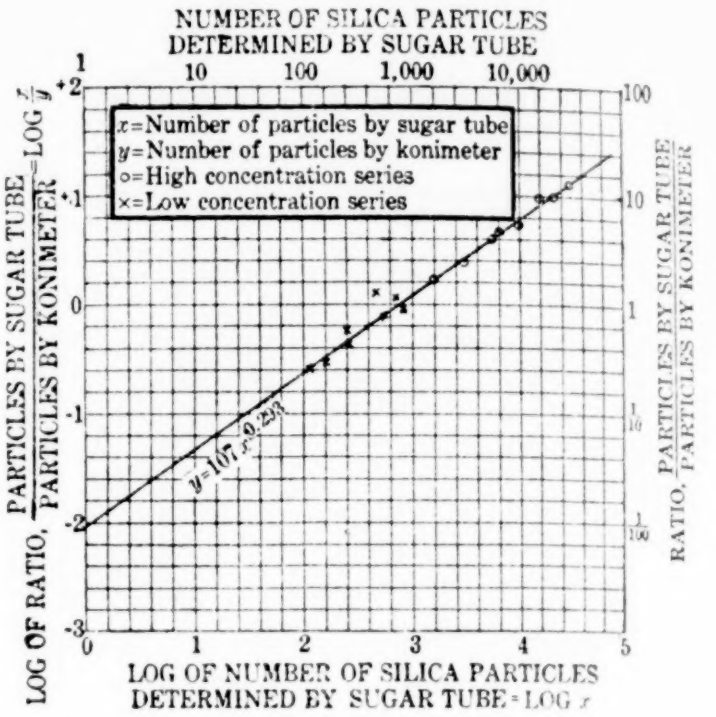
NUMBER OF SILICA PARTICLES DETERMINED BY SUGAR TUBE
1
10
100
1,000
10,000
x=Number of particles by sugar tube
y=Number of particles by konimeter
o=High concentration series
×=Low concentration series
y=10^1.x^0.293
LOG OF RATIO, PARTICLES BY SUGAR TUBE / PARTICLES BY KONIMETER = LOG x/y
RATIO, PARTICLES BY SUGAR TUBE / PARTICLES BY KONIMETER
LOG OF NUMBER OF SILICA PARTICLES DETERMINED BY SUGAR TUBE = LOG x

Fig. 1.—Change of sugar tube : konimeter ratios of silica particles with variation in dustiness.

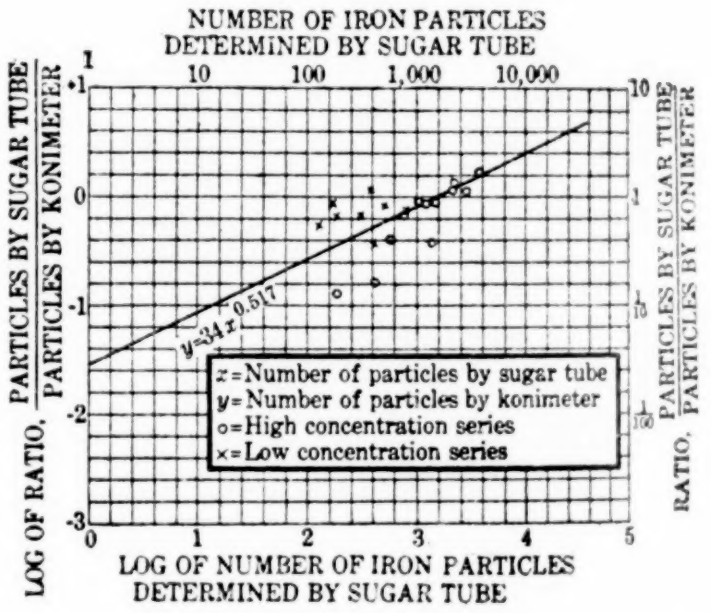
NUMBER OF IRON PARTICLES DETERMINED BY SUGAR TUBE
1
10
100
1,000
10,000
y=34 x^0.517
x=Number of particles by sugar tube
y=Number of particles by konimeter
o=High concentration series
×=Low concentration series
LOG OF RATIO, PARTICLES BY SUGAR TUBE / PARTICLES BY KONIMETER
RATIO, PARTICLES BY SUGAR TUBE / PARTICLES BY KONIMETER
LOG OF NUMBER OF IRON PARTICLES DETERMINED BY SUGAR TUBE

Fig. 2.—Change of sugar tube : konimeter ratios of iron particles with variation in dustiness.

konimeter obtained with silica dust are given graphically in Figure 1. Logarithmic scales are used on the graph because of the wide range of the numbers, and because the straight line indicated thereon gives a better idea of the fit of the data. The line, where extrapolated beyond the range of the data, does not represent de-

termined facts; the extrapolation is made over the width of the graph for comparison with the data on Figure 3.

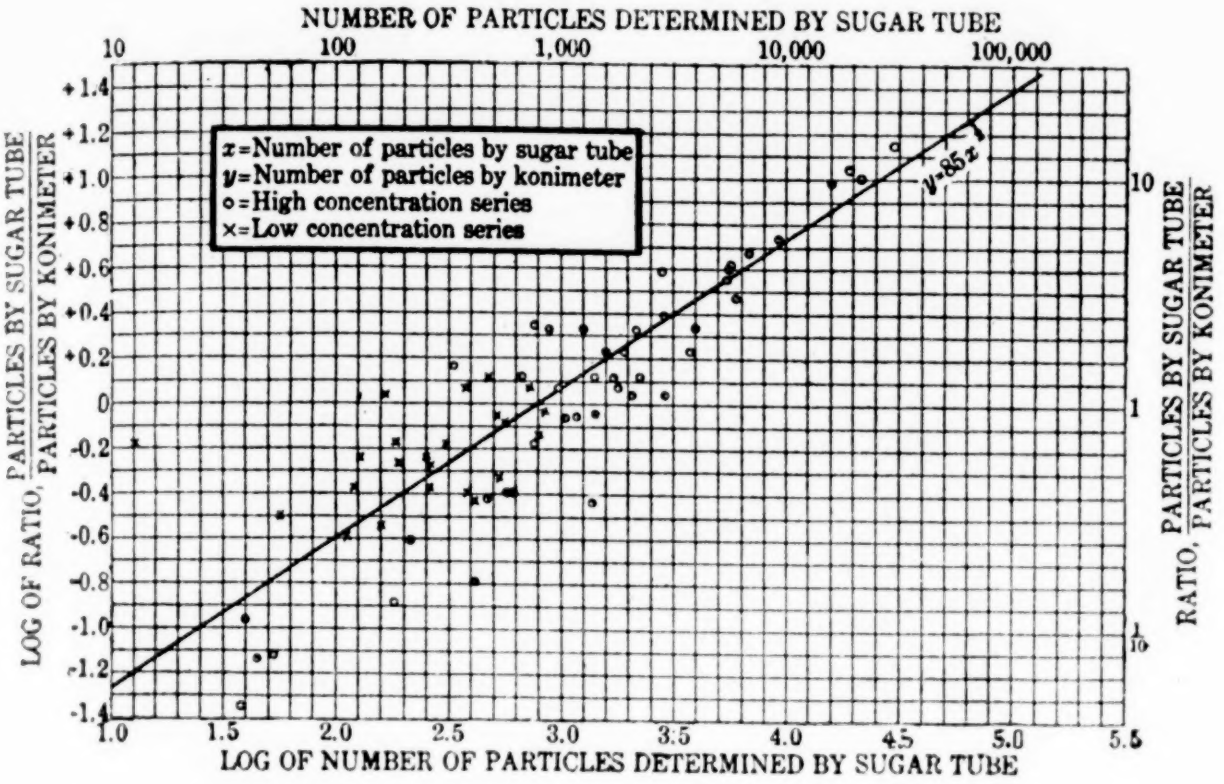

FIG. 3.—Change of sugar tube : konimeter ratios with variations in dustiness, including all kinds of dust except granite.

Figure 2 represents the results obtained with iron metal dusts which gave the poorest fit of any dust, because the iron was corroded by the sugar solution and probably some was dissolved. The trend, however, is still apparent.

The results of tests with all dusts under the regulated conditions (excepting the granite dust tests mentioned) are grouped in Figure 3. The direction of the line was determined by averaging the respective ordinates and abscissas of the higher and lower groups of points. Figure 4 shows the same relation as that indicated by the line on Figure 3, plotted on the more usual numerical co-ordinates instead of on the co-ordinates of logarithms.

Each sugar tube sample was taken over a period lasting fifteen minutes; during this time seven samples were taken with the konimeter and the average was compared with the results of the sugar tube test. Three or four successive sugar tube samples, each with seven corresponding konimeter samples, were taken from each suspension of dust. The larger and heavier dust particles naturally tend to settle more rapidly, leaving smaller particles in suspension. The points on the figures marked o represent samples from suspensions originally high in concentration: those marked x are from suspensions originally low. As indicated in Figure 3, the concentrations of dust of the high and low series overlap. This is due to settling, a tendency which diminished the original high concentrations. The circles at low concentrations (low abscissa on Fig. 3) result then from suspensions from which most of the larger particles had precipitated. The ratios indicated by the circles are generally lower than the x's at corresponding abscissas. A low ratio results from correspondingly higher determina-

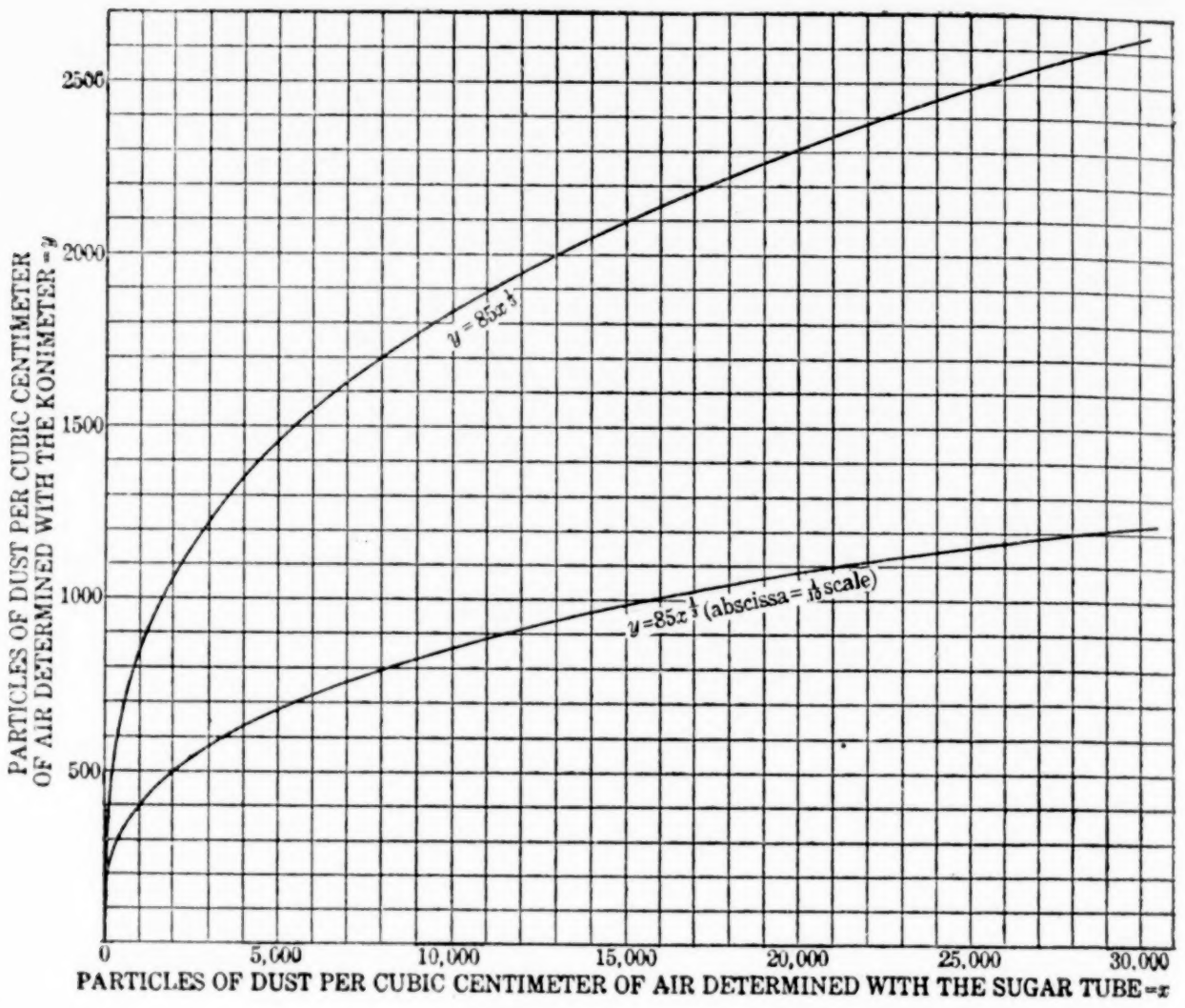

FIG. 4.—Relation between the number of particles of aerial dust determined with the konimeter and the number determined with the sugar tube.

tions with the konimeter and these in turn must be due to less superposition. This may be expected from smaller particles, and is further evidence of the effects of superposition. The general trend, however, everything included, is toward decreasing ratio with lower concentrations.

Figure 5 groups together the graphs for each dust of the series of comparative tests, the graph (taken from Fig. 3) inclusive of all these dusts sampled under regulated conditions, and also the graph for tests formerly made in granite cutting plants at Barre. The agreement is not close, but the general trend is the same, and all the graphs indicate that the ratio of the numbers of particles determined by the sugar tube to the numbers determined by the konimeter increases with increasing dustiness.

EQUATIONS FOR CONVERTING DUSTINESS IN TERMS OF ONE INSTRUMENT INTO TERMS OF ANOTHER

Algebraic equations representing each line on Figures 1 to 5 are given alongside the lines. The general form is

$$y = ax^b \qquad (1)$$

where x = particles determined by the sugar tube, y = particles determined by the konimeter; a and b are constants.

Values of a and b found for the different dusts are as follows:

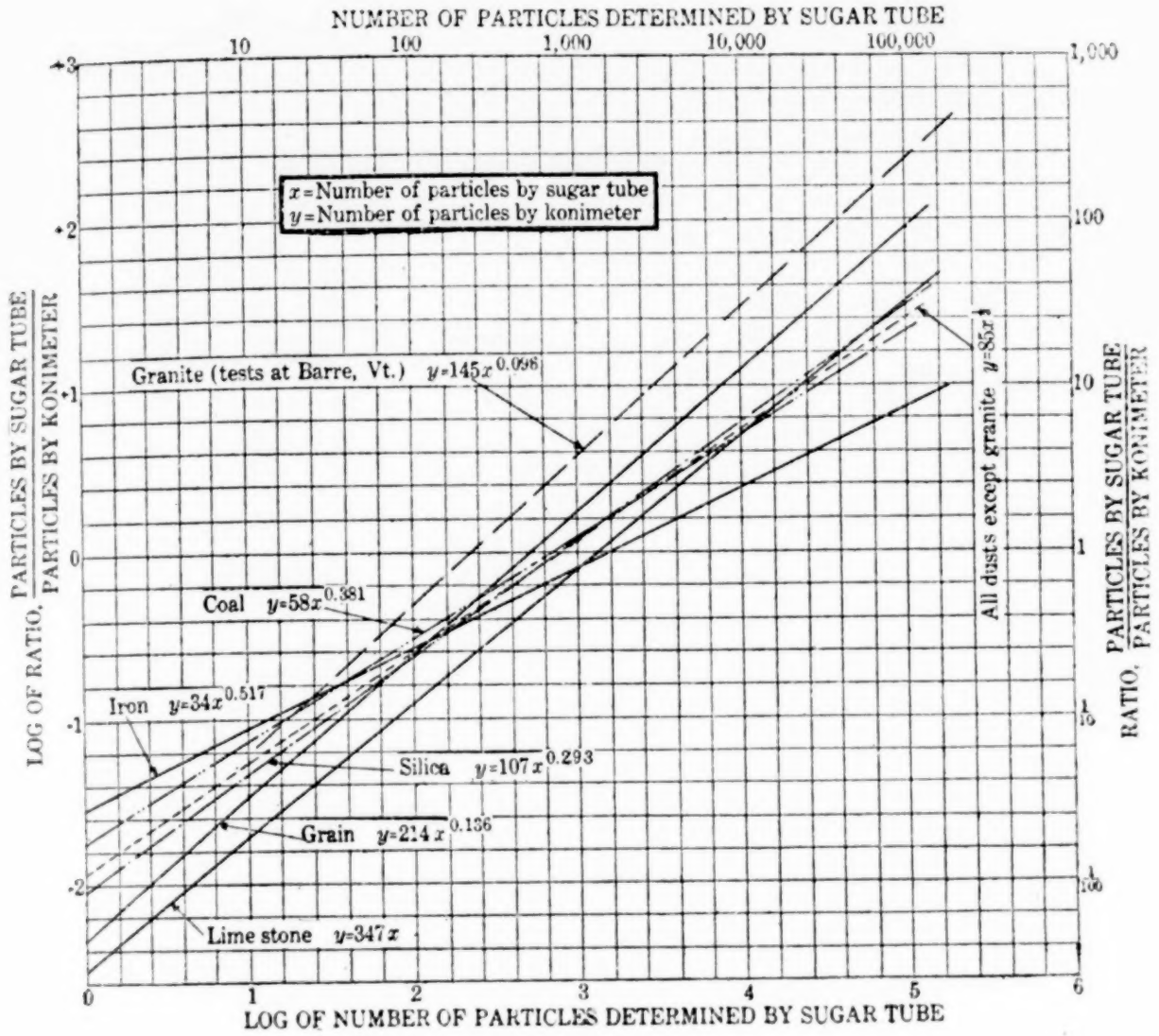

FIG. 5.—Comparison of changes in sugar tube : konimeter ratios for different dusts.

Type of Dust	*Value of a*	*Value of b*
Coal	58	0.381
Grain	214	0.136
Iron	34	0.517
Limestone	347	0.193
Silica	107	0.293
All above dusts	85	0.333
Granite	145	0.096

The conversion of dustiness from terms of sugar tube to terms of konimeter, and *vice versa*, is best done by means of the respective equations. The values of a and b for each dust should be used in calculations for the respective dusts or for a like dust, if the similarity is known. If another dust whose properties are not known is to be considered, the values of a and b (85 and 0.333) derived from all the dusts should be used.

Should the comparison of the konimeter results with those of another dust determining instrument other than the sugar tube be desired, factors which have been determined for the sugar tube compared with the other instrument may be employed. In the comparative tests of dust instruments (1, p. 59), the numbers of dust particles per cubic centimeter of air determined by the impinger and by the Palmer apparatus were found in the ratios of the following figures where the sugar tube is taken as unity:

Impinger	2.4
Sugar tube	1.0
Palmer apparatus	0.5

The factor for converting dustiness determined by the impinger into the terms of the sugar tube is then $\frac{1}{2.4} =$

0.4; similarly for the Palmer apparatus the factor is $\frac{1}{0.5} = 2$. These factors did not change with the degree of dustiness.

If z represents the dustiness determined by the Palmer apparatus, then

$$x = 2z \qquad (2)$$

which, substituted in equation 1, gives the relation between the konimeter and the Palmer apparatus thus:

$$y = a(2z)^b \qquad (3)$$

Similarly for the konimeter and the impinger the relation is

$$y = a(0.4z)^b \qquad (4)$$

Equations 3 and 4 may be used accordingly for converting dustiness into terms of the respective instruments.

The factors stated before are medians derived from considerable numbers of comparative tests, because close agreement between individual tests is unusual in dust determinations, even with the best methods and technic now known. The factors are probably the best determined today, but may be modified when improved methods or more extensive investigations determine others more accurate.

Conclusions

1. The ratio of the numbers of particles of dust in air determined with the sugar tube to the numbers of particles determined with the konimeter increases as the dustiness increases; the relation found is expressed by the empirical equation

$$y = ax^b$$

or, particles determined by the konimeter = a(particles determined by the sugar tube)^b, where a and b are constants.

2. Conversions of dustiness in terms of the sugar tube into terms of the konimeter are best made by means of the foregoing equation; values of a and b are stated for dusts of coal, grain, iron, limestone, silica, and granite.

3. A similar relation holds for the konimeter and the Palmer apparatus or the impinger.

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THE EFFECT OF TURBULENT AIR MOTION AND OF HUMIDITY ON THE STABILITY OF DUST, FUME, AND SMOKE CLOUDS*

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IN a recent paper (1) we discussed the adaptation of photometric methods, particularly Tolman and Vliet's Tyndallmeter, for estimating the strength of liquid and gaseous suspensions, both stable and unstable. As its name implies, the Tyndallmeter is a device for measuring the strength of the Tyndall beam. It permits the user to work with reasonable accuracy and very rapidly. In dust problems, speed of observation is often of prime importance because the suspensions under study are unstable and changing continually both in concentration and in physical character.

Offsetting the advantage of facilitating rapidity of determinations, the Tyndallmeter method has a number of disadvantages. First, it depends on measuring reflected or scattered light, and the instrument is, therefore, sensitive to changes of color and size of the particles which cause the reflection or scattering. Second, the relation between concentration and Tyndall reading, within certain limits, is linear, but when the concentration becomes too dense this relation no longer holds. Third, it is impossible to prevent a slight amount of stray light from being reflected within the examining chamber of the instrument itself, so that clear media give readings above the lowest theoretic reading obtainable on the instrument. Fourth, the sensitivity of the instrument for very low concentrations is questionable—an objection which applies particularly to gaseous rather than to liquid suspensions.

* Received for publication April 7, 1926.

SIZE OF DUST, FUME, AND SMOKE PARTICLES

Dust, as encountered in industry, consists of finely divided solid material of which the individual particles range in size from approximately 150 microns to 1 micron (or less), with the median size usually under 10 microns.

The silica dust used in certain of our experiments was furnished by the Corning Glass Company, and is a ground product containing over 99 per cent. SiO_2. The particles range from about 0.5 micron to over 30 microns in size, with the median falling between the approximate limits 1 to 3 microns. Of the suspensions we used, the silica is the least uniform.

Freshly formed zinc oxide fume particles are about 0.6 micron and very uniform. Those of the fine zinc oxide powder, a special product of the

New Jersey Zinc Company, are still smaller and are also uniform. Suspended in air the effective size of both types of oxide may be larger owing to particle aggregation.

The size of tobacco smoke particles, according to Wells and Gerke (2, p. 323), is 0.27 micron, with a variation of about 2 per cent. In general the uniformity increases as the size of the particles in the several suspensions decreases.

Experimental Procedure

Production of Dust, Fume, and Smoke Clouds

Dust clouds can be produced in the laboratory in a number of ways. A convenient method is to blow the dried dust into a large gas tight cabinet (3) by means of a "suction tee" actuated by compressed air. Zinc oxide fumes can be made by blowing oxygen over the boiling metal or by blowing an inert gas, like carbon dioxide, through zinc ethyl. A more rapid method is to explode a mixture of about 4 parts of zinc powder with 1 part of potassium chlorate. Clouds thus produced are accompanied by impurities such as unburned metal and potassium chloride and chlorate. Tobacco and other carbonaceous smokes are made by igniting the appropriate mixtures and then blowing air through the ignited mass.

In the experiments described in this paper Tyndallmeter readings were recorded shortly after the cloud under examination became uniformly distributed in the gas cabinet. Then and then only do the Tyndall readings begin to decrease with definite regularity. Readings were always made under like conditions and the meter was standardized[1] before, and sometimes during, each experiment. With nearly all gaseous suspensions, particularly dusts, frequent cleaning of the meter is essential.

Production of Turbulent Air Motion

Turbulent air motion was produced by two portable oscillating fans, placed opposite each other within the cabinet and controlled outside. The velocity of the air currents produced by these fans varied from approximately 15 to 1,000 feet per minute, depending on where and when the measurements were taken.

Production of Humidity

A convenient laboratory method of increasing atmospheric humidity, either as vapor or as mist, is by jets of steam. In order to study the effect of local humidification we first set up the dust, fume, or smoke cloud in the cabinet; when the suspension began to settle regularly we blew in steam. When general humidification (high percentage of relative humidity) was desired, we brought the air of the cabinet to the saturation point, allowed the fog to subside until the air was about 95 per cent. saturated, and then introduced the dust, fume, or smoke cloud. Since the Tyndallmeter is sensitive to fog particles (most dust measuring devices are not), it was possible to tell by Tyndall readings when the atmosphere had passed below the

[1] The method of standardization was discussed fully in our previous paper (1).

saturation point. The actual degree of saturation we determined by appropriate psychrometers and checked the readings occasionally with sling psychrometers.

Effect of High Concentrations

It is well known that high concentrations of dusts, fumes, and smokes are unstable. In the case of dusts the particles in a typical cloud cover a wide range of sizes. In still air the large particles settle out first so that decreasing concentration causes a gradual decrease in the size of the particles remaining in suspension. The gradual change in the rate at which dust particles settle is shown in Figure 1, curve A.

In the case of freshly formed fumes of substances like zinc oxide, settling is affected primarily by the tendency of the particles to aggregate into groups and even to grow (2, pp. 325 to 328) (4), until their combined weight is sufficient to cause them to settle. Here high concentrations promote aggregation by increasing the chances of collision between the particles. Consequently fume suspensions of high concentrations are less stable than those of low concentrations. This effect is obvious in Figure 3, curve A.

The visible part of smokes, like those from burning tobacco, consists mainly of ultramicroscopic droplets of water condensed about nuclei of carbon or tar. The collision of particles in such suspensions results in the formation of larger droplets, rather than in aggregates of dry particles. The formation of these larger droplets may account for the gradual change in the slope of the settling curve shown in Figure 4, curve A.

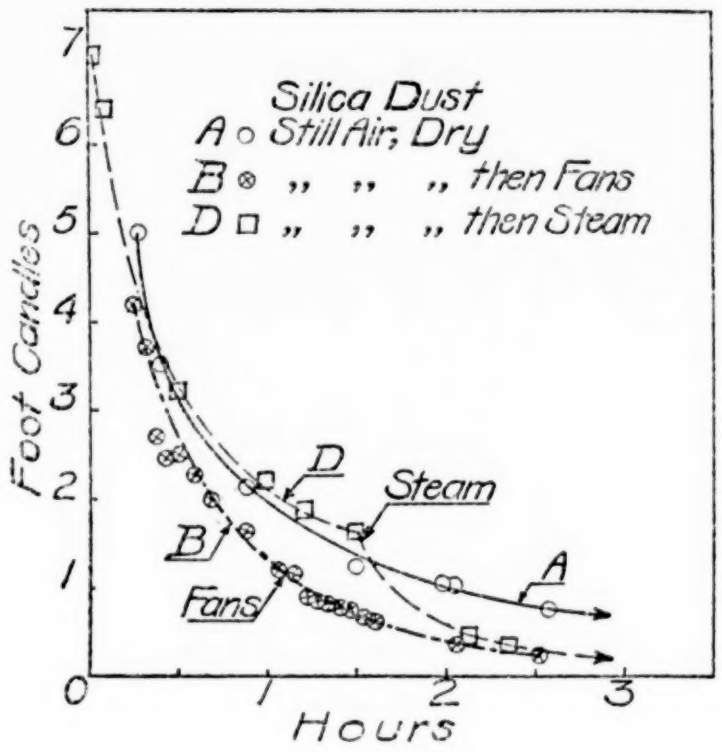

Fig. 1.—Effects of turbulent air motion and of steam jets (local humidification) on the stability of silica dust clouds. Dry air refers to normal room air with about 50 per cent. relative humidity—not chemically dried air.

Effect of Air Motion

It was shown by Tolman and his associates (5) that most fumes and smokes clear up more rapidly if the air is stirred up than if it is still. Tolman was interested particularly in the effect of air motion on the stability of fumes and smokes applicable to or analogous to those used in chemical warfare. The object of our experiments was to apply his method to suspensions, particularly zinc oxide, of common hygienic significance and also to use suspensions differing markedly from each other in physical character.

The first part of curve B, Figure 1, applies to still air conditions for silica dust. After a little more than one hour the oscillating fans were started. A slight momentary effect is then

indicated, but the magnitude of this effect is not greater than the errors inherent in the photometric method used

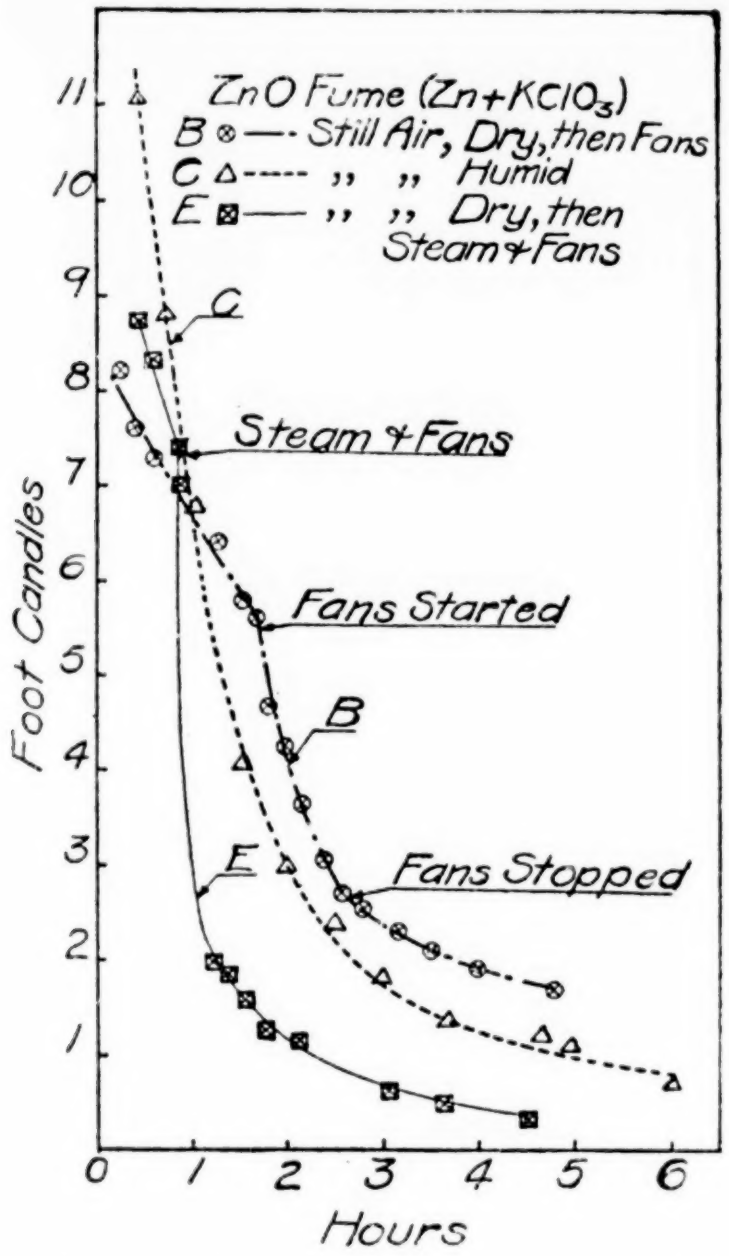

FIG. 2.—Stability curves of zinc oxide fume made by exploding zinc powder and potassium chlorate. Note the effects produced by turbulent air motion and by steam jets. Both cause the particles to aggregate into units large enough to fall out of the suspensions.

for judging stability. The concentration at the time the fans were started was about 150 to 100 mg. per cubic meter, an amount which was estimated but not determined quantitatively. The string of points following closely on the starting of the fans shows that the air motion, produced by the fans, had no measurable effect on the stability of the cloud.

The physical characteristics of the suspensions of zinc oxide fume, represented in Figures 2 and 3, are not unlike some of those investigated by Tolman. The effect produced by the fans (Fig. 2, curve B) is undoubtedly significant. In Figure 4, curve B, the effect of air motion on tobacco smoke is shown. Here again the effect of the air motion is significant. In both cases the air currents promoted aggregation—an effect which was not apparent in the case of silica dust.

EFFECT OF HUMIDITY

Local Humidification.—In mining operations, where dust constitutes either a health or an explosion hazard, water blasts or sprays are often used to keep the dust wet and to prevent its being blown into the air. The removal of dust already suspended in air is a harder problem. Provided dustiness cannot be prevented, it is generally agreed that ventilation furnishes the best means of reducing it, but often adequate ventilation is impractical. In this event the effect of local humidification is of interest.

The efficiency of water blasts in removing dust thrown into the air by blasting has been found by Warren (Australia) (6) to be about 55 to 95 per cent. estimated by gravimetric sampling, and 62 per cent. estimated by konimeter. During dry drilling Harrington (United States) (7) found that external water blasts improved conditions but little if at all. Gray (South Africa) (8) stated that ". . . . water blasts and sprays fail to bring down the really fine dust." Discussing the use of Belger's fluid, a special dust wetting medium, Pirow

(South Africa) (9, p. 62) has written that: "The position on the phthisical mines to-day may be summed up by

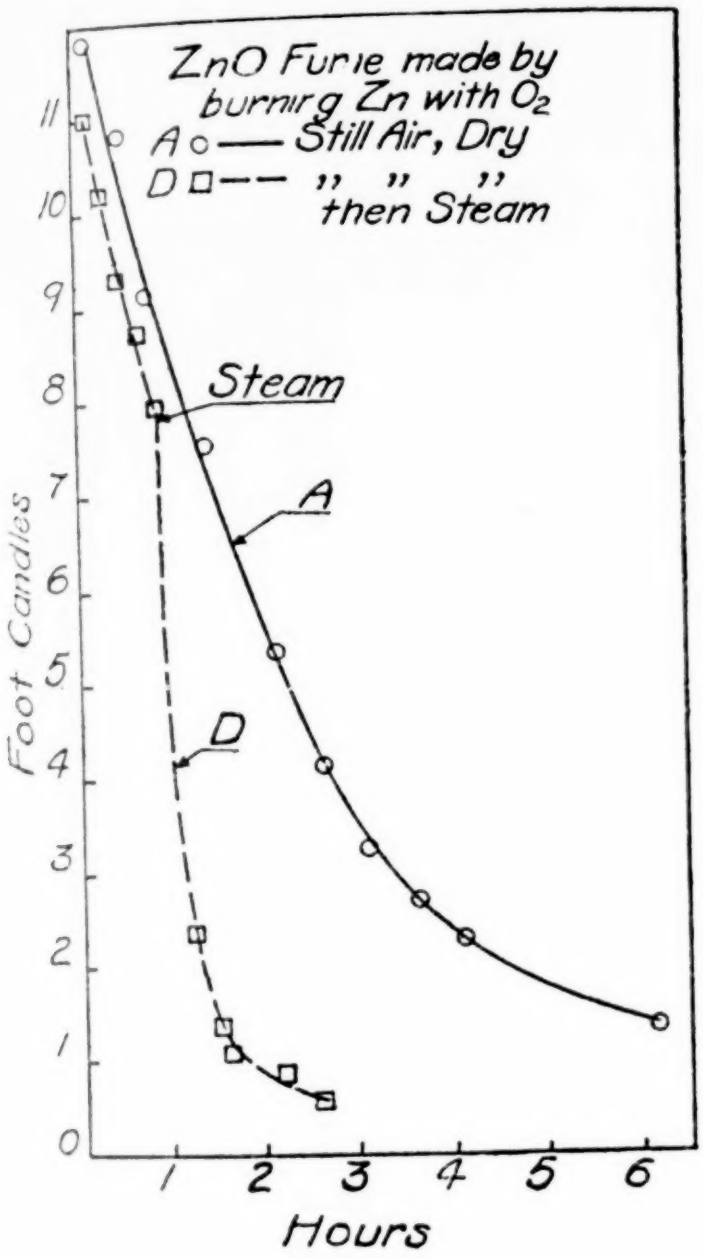

FIG. 3.—Stability curves of pure zinc oxide fume made by blowing oxygen across boiling zinc.

stating that, as far as possible, dust is prevented from entering the mine air by the use of water, and ventilation is looked to to sweep fine dust out of the mine or to dissipate it."

These statements appear to express the general opinion of mining engineers, namely, that external sprays as they are now used in practical mining operations are of doubtful hygienic benefit and are far less effective than the wet drilling of rock and the watering of dusty places.

It is known that basic oxides give, in air, particles usually charged negatively, while acidic oxides generally

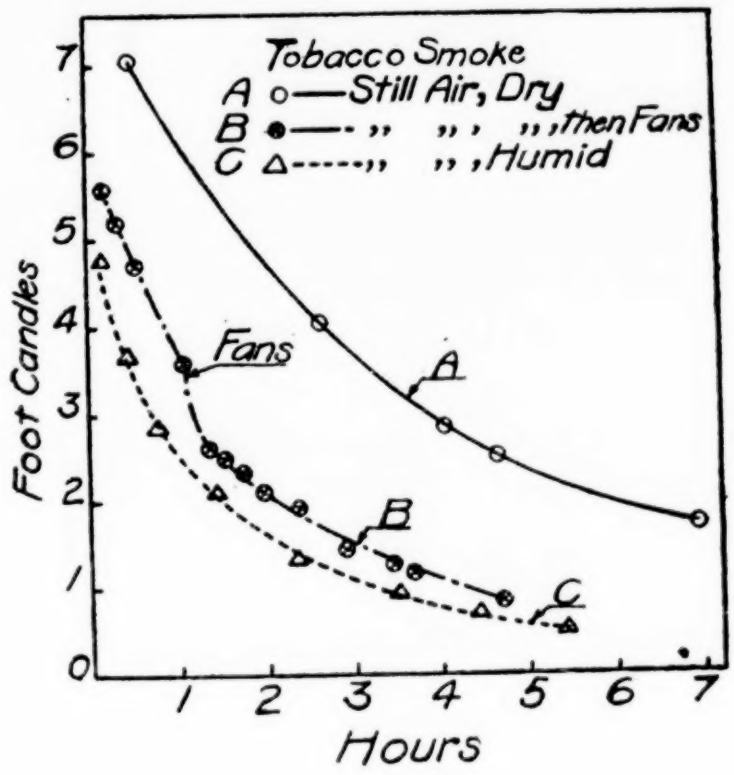

FIG. 4.—Stability curves of tobacco smoke. Air motion appears to exert less effect than on zinc oxide (see Fig. 2). Curve C represents air saturated with moisture before the smoke was introduced—*i.e.*, general humidification.

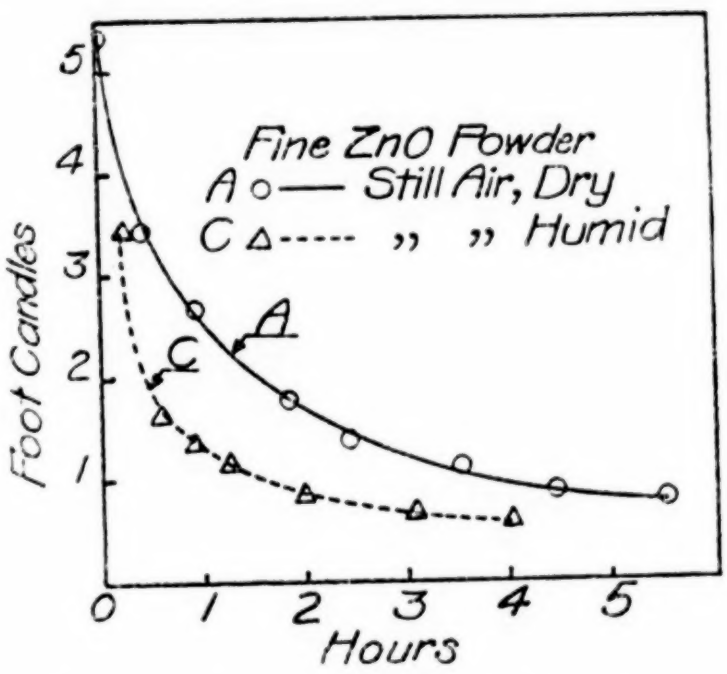

FIG. 5.—Comparative stability of suspensions of fine, previously dried zinc oxide powder in humid and in normally dry room air.

acquire a positive charge (10). Water sprays and steam jets, according to Gibbs (11), give mainly positively charged particles. It would seem

probable that particles like zinc oxide, negatively charged, would be more affected by steam jets (Figs. 2 and 3, curves E and D, respectively) than would positively charged silica particles (Fig. 1, curve D). This is indicated but not proved by our results.

General Humidification.—Occasionally general, as distinguished from local, humidification, is advocated as a method of reducing dustiness. Provided the concentration of particles is high, general humidification has a considerable effect on a fine powder like zinc oxide (Fig. 5, curve C), zinc oxide fume (Fig. 2, curve C), possibly a slight effect on tobacco smoke (Fig. 4, curve C), but probably none on a dust like silica (our "general humidification" curve for silica was too much like the dry air curve, Figure 1, to permit any positive conclusions and is, therefore, omitted).

Discussion

We have made no distinction between reduction of concentration by settling to the floor and by collision with or diffusion to the walls of the cabinet. The ratio of volumes to the area of walls and ceiling in our cabinet is 0.43 to 1 and in Tolman's (5) cabinet probably was about 5 to 1. Other things being equal, the chances of diffusion to and collision with the walls and ceilings are about ten times as significant in Tolman's as in our cabinet. Neither set of experimental observations can be applied indiscriminately to industrial conditions. The data show relative and not absolute effects.

Temperature differences between the air inside and outside our cabinet were not more than 2 or 3°F. Consequently diffusion or convection currents from temperature differences are unimportant. The introduction of steam, however, causes marked currents due both to temperature differences between the steam and air and also to increase in the gas volume. The latter effect decreases as the steam condenses and in all lasts but a few moments. The substitution of compressed air driven water sprays for the steam jet would not obviate these difficulties.

We have pointed out that the Tyndallmeter measures dispersions which may or may not be related in linear form to concentrations. That is, a definite Tyndall reading in foot candles may signify different concentrations for different suspensions even though these suspensions are alike chemically. For instance in dusts, such as silica, like Tyndall readings can be obtained on silica suspensions differing in concentration by as much as 100 per cent., on fine zinc oxide powder by about 20 per cent., on freshly generated zinc oxide fume by about 5 to 10 per cent., while tobacco smoke, which we cannot estimate in terms of concentration, probably gives smaller discrepancies.

Also like Tyndall readings on the zinc oxide suspensions in Figures 2, 3, and 5 do not represent equal concentrations either of numbers or of weights of particles. They may differ by as much as 100 per cent. because of differences in the size of the particles in the different suspensions.

At first sight these discrepancies, particularly for silica, seem large, but it should be remembered that it is by no means proved that dispersion, as

estimated photometrically, is not a better hygienic measure of air pollution than concentration, whether of numbers or of weights. Dispersion may give a truer picture than does concentration of chances of solution, fibrosis, or phagocytosis, all of which are primarily surface phenomena.

Summary and Conclusions

Clouds of dusts, fumes, and smokes were set up in a 1,600-cubic foot gas tight cabinet and gradual changes in the suspensions were followed by a Tyndallmeter attached to the side of the cabinet. Turbulent air motion was found to have no effect on silica dust, a marked effect on freshly generated zinc oxide, and a considerable effect on tobacco smoke. Local humidification (steam jets) had a marked effect on silica dust and on zinc oxide.

General humidification (increasing the percentage of relative humidity of the air in the cabinet) before introducing the various suspensions caused zinc oxide, both as powder and as fume, to settle out more rapidly than in dry air but exerted only questionable effects on silica dust and tobacco smoke. The methods by which the various clouds were generated and the size of the particles in each are discussed.

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BOOK REVIEWS

FACTORY LEGISLATION (BRITISH) AND ITS ADMINISTRATION. 1891–1924. By *H. A. Mess*. P. S. King & Son, Ltd., 1926.

The story of British factory legislation which commenced with the nineteenth century has several times been told. But it has naturally ceased with the period reached at the time each work was published. The present book resumes the narrative where others have left it and brings it up to date. The time chosen for a start is ten years before the end of the last century; a time when special rules governing dangerous trades were first introduced, which have since become the foundation of an ever-extending control over dangerous processes; when trade unionism was revived; when the first labor member entered Parliament; when the first international labor conference was held; and when the first woman inspector of factories was appointed.

The first chapter is devoted to a summary of factory legislation prior to 1891, wherein it is shown how most measures have been compromises, and how the factory Acts were a mass of anomalies and inequalities and of special regulations. The progress of legislative advance with a factory Act in 1895, and the subsequent Consolidating Act of 1901, is next traced as far as the war period. During this stage greater tendency can be detected for legislation to proceed on the recommendations of expert commissions and committees, and as the result of special inquiries, rather than as an answer to some popular but not necessarily well-informed outcry. Matters dealing with the conditions in cotton mills, with truck, with compensation and the prevention of accidents, with the abolition of white phosphorus, and with the advance of international labor opinion are all discussed in due sequence. This period, so far as health is concerned, is chiefly marked by the adoption of code after code of regulations aimed at the prevention in different industries of special health risks, such as lead poisoning, dust inhalation, and anthrax infection.

Next came the war and postwar periods, of which the outstanding feature has been, acting through what are known as welfare orders, to aim at maintaining the health of those employed in contradistinction to the previous objective of merely removing risk. Action of this kind has been even more surely based on appeal to scientific knowledge than that which occurred heretofore. The way in which the law is enforced by the inspectorial staff is told, and commendation is given to the influence so exerted by spreading information and by peaceful persuasion, rather than by punitive action. Meanwhile trade unionism has been moving forward and, though still preoccupied with wages and hours, is, through joint industrial councils, coming to take more interest in the objectives of factory legislation and health and contentment; Whitley Councils have been influential in this direction. One gap is noted in present factory law

with regard to the absence of any limitation of hours of labor for male workers; indeed, even for the protected class, the women and young persons, legislation today lingers far behind practice, which has stereotyped the eight-hour day. Attention is drawn to the way other legislation has affected industry, such as the education Acts, the compensation Acts, trade boards Acts, national health insurance, and legislation for housing and town planning. Just as during the last century, there has been during the past twenty-five years a considerable amount of piecemeal factory legislation, and today a consolidating Act is badly needed to simplify administration and procedure.

This volume cannot fail to be of great value to all interested in British factory legislation as an example of sound public health enactments. The facts are plainly stated with great accuracy; the time is by for picturesque description of startling and depressing features in factory life; they were swept away during the last century. Only in one respect do we regret an omission in that no reference is made to the simultaneous growth of legislation for coal mines. The way in which during the last century some new point first appeared in a factory or in a mines Act, and then was improved upon and embodied in legislature for the other code, has always been of interest; and the process is still continuing. The hours of adult male labor are now limited for coal miners by Act; the factory operative awaits the same. Welfare conditions of work are controlled in factories; the miner only has advantage from a semivoluntary welfare scheme which deals merely with the social conditions of his life outside working hours. The influence of these two codes of legislation, one upon the other, should not be disregarded.—*E. L. Collis.*

LIGHT AND HEALTH. A DISCUSSION OF LIGHT AND OTHER RADIATIONS IN RELATION TO LIFE AND TO HEALTH. By *M. Luckiesh*, Director, Lighting Research Laboratory, National Lamp Works of General Electric Co., and *A. J. Pacini*, Director, Department of Biophysical Research, Victor X-Ray Corporation of General Electric Co. Cloth. Pp. 302 with illustrations and index. Baltimore: The Williams & Wilkins Co., 1926.

The first chapter is a presentation of the physical nature of light and radiation; frequency, wave length, ultraviolet, visible, infra-red, solar radiation, transmission factors of various glasses for solar and artificial illuminants, and spectral analyses are discussed. Climate, particularly from the standpoint of light, and the human race are discussed in the second chapter and attention is called to the fact that the blond races fare better in northern climates than do brunettes, while in southern climates the reverse is true. In the third and fourth chapters the photochemical and physiologic analogy between chlorophyll in plants and hemoglobin in animals is pointed out and the fact that we, in the twentieth century, are again reverting to the sun worship practised by the ancients.

In the fifth chapter, on light and skin, the authors discuss erythema, sunburn, pigmentation, photo sensitization and certain diseases of the skin which lend themselves to phototherapeutic treatment. In Chapter VII, on light and the skeleton, they discuss phototherapy and calcium

metabolism in relation particularly to rickets, tuberculosis, dental caries, and bone fractures—all fields in which phototherapy has achieved notable results.

The chapters on light and the muscles, nerves, and viscera present no especially convincing arguments on the omnipotence of energy, except as heat, in its direct or indirect effects. Some space, however, is devoted to metabolism, particularly of calcium, in its relation to visceral disturbances and this makes a place for a pertinent section on ultraviolet radiation and calcium metabolism.

Chapter XI on light and infection is devoted mainly to the bactericidal effects of ultraviolet light, a field in which ultraviolet radiation and heliotherapy have been so extensively applied. The next chapter, on light and hygiene, continues in somewhat the same vein but discusses also the function of ultraviolet light in relation to foodstuffs. "At the present time the difference between an oil with food-value and one lacking in food-value is attributed to the presence of vitamines in the first which are lacking in the second. But it is evident in the light of recent discovery that even the so-called vitamines are not alone responsible for this important difference in food-value; sunlight or other radiations are found to be involved in the mystery."

In the chapter on light and the senses the authors discuss the acclimatization of the eye to radiations within the visible spectrum and the physiologic significance, to the eye, of radiations above or below the visible in wave length. The book then concludes with two chapters dealing with the psychologic effects of light and the effects on the eye of good and bad artificial illumination.

This book gives a modern picture of the general subject of radiation therapy and more particularly of phototherapy and heliotherapy. The authors have drawn freely from the work of others so that much original research is collated and analyzed in their book. The technical reader may regret the lack of an author's index and of references to the literature but he will, none the less, find ample matter, presented in simple and pleasing style, to repay him for reading this book.—*Philip Drinker.*

BOOKS RECEIVED

Books received are acknowledged in this column, and such acknowledgment must be regarded as a sufficient return for the courtesy of the sender. Selections will be made for review in the interest of our readers and as space permits.

PSYCHOTHERAPY. MENTAL ELEMENTS IN THE TREATMENT OF DISEASE. By *Edward Wyllys Taylor*, James Jackson Professor of Neurology in Harvard University. Harvard Health Talks, 14. Cloth. Pp. 53. Cambridge: Harvard University Press, 1926.

INTERNATIONAL CLINICS. Volume I. Thirty-Sixth Series, 1926. Cloth. Pp. 309 with illustrations and index. Philadelphia and London: J. B. Lippincott Co., 1926.